Interdisciplinary Research in Physics

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LONG-TERM GOAL

The express purpose given for the creation of this program in 1979 was to promote collaborative research between APL and the various academic units of the University of Washington. Within this framework, our goal is to pursue high quality fundamental research which brings together APL staff and University faculty in new collaborations, ultimately leading to fuller participation of our staff in supervision of undergraduate, graduate student, and post doctoral research. A secondary goal is access to expertise and research facilities available outside APL for Navy-related research. The following four research projects are in their first year.

RESEARCH PROJECTS

Mathematical Aspects of Hamiltonian Theories for the Ocean

Frank S. Henyey (APL)
C. Robin Graham (Mathematics)

OBJECTIVE

Our objective is to determine the usefulness of the Hamiltonian formalism for numerical modeling of ocean flow fields, including internal waves and turbulence, and to clarify the nature of conservation laws.

WORK COMPLETED and RESULTS

Two papers have been prepared for publication. The first is already submitted, and the second should be ready for submission in early November, 1998. The first paper compares two formulations of stratified fluid Hamiltonian theories. The two Hamiltonians are related by a canonical transformation, yet they have different gauge groups. Thousands of papers have been written about gauge groups, primarily about the physics of elementary particles, but this is the first time that it has ever been found that two different gauge groups describe equivalent dynamics. This result led to a deeper understanding of the conservation laws of density and potential vorticity for stratified fluids.

The second paper is concerned with the question of the existence of Hamiltonian representations. We found that, except in unusual cases, the standard Clebsch representation for a homogeneous fluid does not exist in any arbitrarily small region surrounding a point at which the vorticity vanishes. This is very

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surprising and claims to the contrary abound in the literature. On the other hand, the analogous representation for a stratified fluid does exist locally under generic conditions. As the Clebsch representation is a basic ingredient in many applications of the Hamiltonian method, this result may be useful in deciding appropriate regions of space in which to use the representation in various implementations.

We have conjectured that the stratified fluid representation also exists globally in a simply-connected region (*i.e.*, we assume no islands in the region being described) for flows which typically arise in practice. We are attempting to prove or disprove that conjecture. We will also try to find out the situation with an island present.

We have conducted a literature search concerning Clebsch representations and various generalizations, of which there are many. This search has uncovered some Russian literature previously unknown to us which may be relevant. We have also found some work clarifying the role of helicity and topological considerations in the question of existence of Hamiltonian representations. This insight should prove helpful in settling the conjecture of global existence of the stratified fluid representation.

IMPACT/APPLICATIONS

Hamiltonians are also useful (although not as important) for linear systems. In particular, we are working on the Hamiltonian description of ocean acoustics. It is straightforward to make the narrow-angle parabolic approximation in the Hamiltonian context by simply dropping a term, but we have not yet found out how to make the wide-angle parabolic approximation in a similar way. These results may be useful in handling the boundary conditions at the water-sediment interface.

Investigate Environmentally Adaptive Sonar Controller

Gregory M. Anderson (APL)
Robert T. Miyamoto (APL)
Robert J. Marks II (EE)
Mohamed A. El-Sharkawi (EE)

OBJECTIVE

We plan to assess the applicibility of modern control strategies to the problem of sonar performance optimization, incorporating *in situ* environmental data and real-time model outputs into the control system.

APPROACH

We are making good progress toward developing a sonar controller which can automatically tune sonar performance in response to changing ocean environmental conditions. Our approach is to use computational intelligence techniques (e.g., neural networks, fuzzy controllers). We have defined a closed loop controller that addresses many of the important areas of wideband, variable depth sonar control, and have broken the task into subcontrollers which address specific control areas including:

- Doppler Processing, to switch between high and low doppler targets

- Ping Frequency and Bandwidth, to accommodate varying environmental clutter response to frequency
- Ping Type, for selecting LFM, HFM, CW, and other pulse type considerations
- Signal Excess Optimizer, to select beam shape, tilt, and depth of the sonar
- Ping Schedule, to provide an mix of pings that accomplish high level tactical goals
- Probability of Detection Area Control, to position (e.g., ships position) the sonar pings.

WORK COMPLETED

We have begun developing a prototype Signal Excess Optimizer (SEO) subcontroller, which is based on experience gained using neural networks (NN) for electrical power grid security assessment and shorted electric motor rotor winding isolation. The SEO is designed to tune the sonar system to environmental conditions to maximize detection coverage over a specified search region. We used acoustic models to train a neural net to environmental (wind, sound speed, bottom characteristics) and sonar (sensor depth) inputs, and produced signal excess values as a function of range and depth. In the current system, 570 acoustic model runs with a wide range of environmental and sonar parameters (over 48 hours of computer time) were used to train a multidimensional, multilayered perceptron NN (12 hours of training). The resulting NN can accurately reproduce the model-computed detection map in less than a millisecond. Our Electrical Engineering colleagues have also demonstrated that the NN can be inverted -- meaning we can determine the sonar parameter settings that provide maximum signal excess, for a specific set of environmental conditions, and a fixed target location. We plan to use the inversion to scan the entire search area to determine combinations of sonar control parameters that will cover the area and meet our tactical goals (e.g., probability of target detection). APL-UW is concentrating on identifying a partitioning of the environmental parameters so that we can apply a multi-layered fuzzy controller to a series of neural nets that will cover a wide range of environments. If we are successful in this effort, we will have developed a tool that allows an operator to mark a region of suspected target depth and range, and the SEO will compute a set of sonar pings that provide the best probability of detection for that target.

IMPACT/APPLICATIONS

The results of this research will be applied in the development of an automated sonar system capable of adapting to changing environmental conditions.

RELATED PROJECTS

We are using this work as a basis for response to a Broad Agency Announcement DD21 Phase 1 Solicitation, entitled "Automated Environmentally Adaptive Sonar Control." Since the controller relies on up-to-date knowledge of environmental conditions, it is related to the Sonar Environmental Parameter Estimation System (SEPES, under development at APL-UW) which extracts key acoustic model inputs (bottom loss, bottom backscatter, surface loss, surface backscatter) from sonar data (reverberation and ambient noise.)

In Situ Measurement Of Porosity

Dajun Tang (APL)
Kevin Williams (APL)
Peter Jumars (Oceanography)

OBJECTIVE

Our primary goal is to further understand the causal factors behind variations in bacterial abundance and activity in marine and estuarine sediments.

APPROACH

We are using an array of electrodes to measure *in situ* sediment conductivity in three dimensions with 1cm resolution. The conductivity measurements will then be converted to sediment porosity distribution with the same resolution. These data will be compared to sediment bacterial activities.

WORK COMPLETED

A series of laboratory tests on the electrodes using glass beads and sands have been successfully conducted. The development of the IMP system is progressing according schedule. It will be ready for field testing by January, 1999. Jill Schmidt, the graduate student partially supported by this project, has developed a calibration method using cores to validate the IMP porosity inversion.

IMPACT/APPLICATIONS

Using IMP, we will for the first time be able to obtain *in situ* three-dimensional sediment porosity data. Such data are critical to validate high-frequency acoustic scattering models. Also promising is the prospect that IMP will provide basis for monitoring sediment biological activities. The results of this research are expected to shed light on *in situ* bioremediation of toxic organic compounds in sediments.

RELATED PROJECTS

Related projects: The IMP will provide an important set of parameters for the High Frequency Sediment Acoustics Research Initiative experiment scheduled for 1999.

Response of Gas-Filled Bubbles to an Ultrasound Beam

Peter Chang (APL)
Steve Kargl (APL)
Udo Schmiedl (Radiology)

OBJECTIVE

Our objective is to understand the physical phenomena related to the interaction of an ultrasound beam with microbubble-based echo-contrast agents used in medical imaging.

APPROACH

Our approach to this project has been to:

- analyze and measure the fundamental physical acoustics of gas-filled microbubbles (ultrasound contrast agents)
- evaluate the acoustic parameters affecting the amplitude and duration of echo-contrast effect
- perform *in vivo* studies (in domestic pigs) using an ultrasound imaging system to verify the usability of microbubbles in improving clinical diagnostic information.

WORK COMPLETED

Our first task was to obtain commercial ultrasound contrast agents for the proposed study. Since most of the agents are not FDA approved, the only way to obtain them was through a research agreement between the University of Washington and the contrast agent companies. We have been working with the following agents: Albunex, Optison, Levovist, Echogen, and MP-1950. We have developed experimental arrangements with different degrees of complexity to perform qualitative and quantitative assessment of the agents, and have found the optimal parameters to tune an ultrasound imaging system to a particular agent. We have used this information to perform experiments *in vivo*, and have shown the utility and limitations of these agents in clinical scenarios.

RESULTS

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The results are best shown by the publications we have been able togenerate so far.

P.P. Chang, I.R.S. Makin and L.A. Crum, Acoustic and system parameters affecting the destruction of ultrasound contrast agents," ICA/ASA, 1191-1192, Seattle, June 1998.

P.P. Chang, P.D. Mourad, S.L. Poliachik, L.A. Crum, Ultrasound Contrast Agents: present but not seen," to be presented at the IEEE Ultrasonics Symposium, Sendai, Japan, Oct. 1998.

P.P. Chang, Optimal acoustic parameters for ultrasound contrast imaging," submitted to the 2nd International Ultrasound and Magnetic Resonance Conference in Vascular Disease, Seattle, Oct. 1998. (invited)

P.P. Chang, U.P. Schmiedl, R.W. Martin, L.A Crum, "Detection of parenchymal organ injuries using an ultrasound contrast agent", submitted to the Meeting of the American Institute of Ultrasound in Medicine, San Antonio, Texas, March 1999.

IMPACT/APPLICATIONS

We have applied gas-filled microbubbles to improve the diagnosis of organ injuries. This work has enormous clinical relevance per se, especially in emergency medicine. In addition, our understanding of the complex interaction between ultrasound and microbubbles/tissues has elicited the participation of some private industries. We have so far obtained enough results to be able to write new proposals along this line of research. We hope this will add resources to the present project and will take it to a level higher than anticipated.